# MATERIAL FLOW RELATIONS IN THE DESIGN PROCESS OF MATERIALS HANDLING

PÉTER TELEK[1]

**Abstract:** Handling relations are often used in every field of logistics, mainly at the design of materials handling processes and systems. Despite this, definitions and determinations of the handling relations are not published in suitable details in the literature. The aim of my research to analyse the handling relations, define the materials handling matrices and their application possibilities in the design process. In this paper I describe the handling relations and the possible devices to take them into account. Beside it, I summarise main types, definitions, characterisations and structures of materials handling matrices, and show their determination methods through a simple example.
**Keywords:** *materials handling, material flow, relation matrix, system design*

## 1. Introduction

Advanced production systems demand efficient materials handling solutions to fulfil the increased requirements. Through this situation realisation of the handling tasks requires the application of higher level design and operation processes.

The design procedure of materials handling contains numerous, different and exactly defined steps which enable effectively (in certain cases: optimal) solving methods for the tasks [1]. The first step of the design of a materials handling process is − in most of the cases − the analysis of the required material flow to determine the base parameters, which depend on the materials handling relations of the system objects. It means that the definition, characterisation and examination of the relations are the basic tasks for the design processes.

In my paper, I summarise the role and characterisation of the materials handling relations, and I present the details of an example for the determination process of the relation parameters to demonstrate their application methods.

## 2. Design process of materials handling

During the design procedure of materials handling, handling tasks of materials, elements, semi-finished and finished products related to the objects of a production or a serving process have to be solved [2]. In generally this is a very complex task, because of the large number of the system objects and handling tasks.

The design procedure is in generally realised in different, but related design steps, as an iterative process [3]. Contents and relations of the individual steps are determined by the characterisation and complexity of the given task, so general solution structure cannot be described. *Figure 1* shows a theoretical algorithm for the design, which contains the main steps of the procedure.

---

[1]   PhD, University of Miskolc
alttelek@uni-miskolc.hu
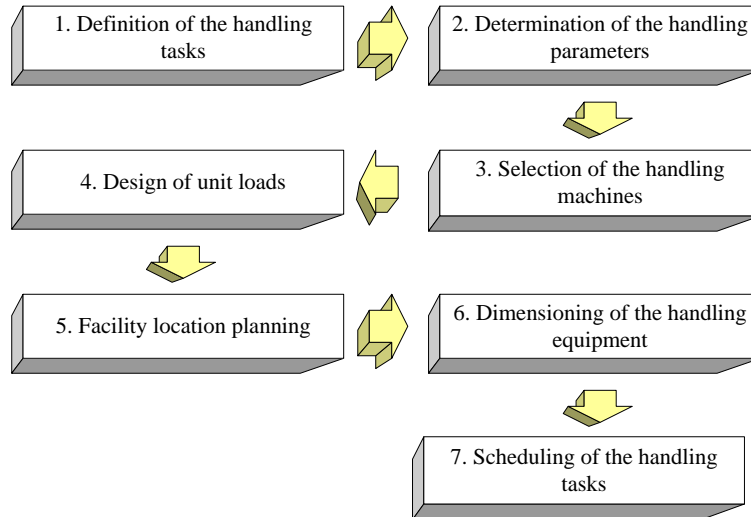H-3515 Miskolc-Egyetemváros, Hungary

*Figure 1. Design steps of materials handling*

At different areas of the industry, general design tasks are based on exact, previously defined input parameters (mainly at the machine design), so the design process means only the application of the given methods [4]. However at the design of materials handling, base parameters come from the served production system and they cannot be counted as the input parameters for the handling system. Because of it, the first step of the design of all materials handling processes is the determination of the handling tasks and their parameters.

The most important task of handling processes is the moving and its related activities (loading, storing etc.) of goods among the objects. All individual moving activities have to be linked to two given system objects, which is named as material handling relation and these relations are the basis for all of the design steps (equipment selection, location planning etc.) of the materials handling processes [5].

## 3. Materials handling relations

Materials handling relation means a special connection between two objects (production or service objects) which contains any kind of handling activity. Handling relations can be defined by the two linked objects and one handling parameter existing among them [5]. In the aspect of handling requirements, handling relations can be always described between one source and one destination object, by the next mathematical formula:

$$r_{ij} = a \tag{1}$$

where
  $i$ – source object,
  $j$ – destination object,
  $a$ – value of the handling parameter, existing between the objects.

There are some differences within the relations depend on the role of the handling process, because at the realisation of the handling tasks we can also determine relations between two source or two destination objects (e.g. collection systems) [6].

Handling relations in generally involve one handling parameter and its value describes the characterisation of the object relation during the design and operation of the handling process. The most important parameters used in handling relations [5]:

- materials and their quantities,
- distances and routes among the objects,
- materials handling costs,
- handling time requirements,
- handling circumstances and conditions,
- disturbing objects and problems etc.

Materials handling relations can be defined and demonstrated by different methods:

- describing individual handling relations,
- using handling process charts,
- using materials handling graphs,
- using materials handling matrices etc.

### 3.1. Individual relations.

Handling processes can be described using individual handling relations if the number of the objects and the relations are small. In this case all of the relations have to be defined individually, using the best suited parameters for the all of the given relations. This method gives quick and clear results at simple handling processes, but it cannot be applied for complex materials handling.
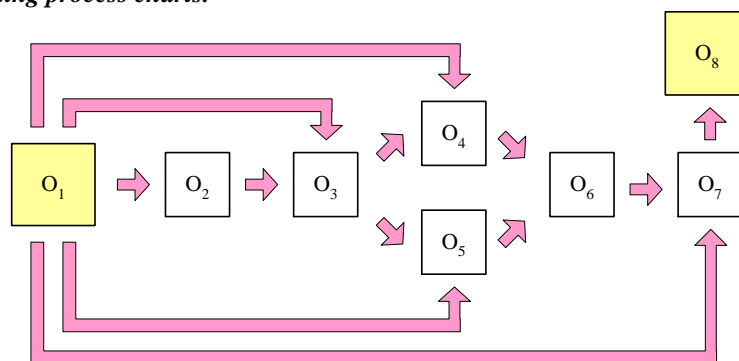
### 3.2. Handling process charts.



*Figure 2. Example for a handling chart*

Another possibility to demonstrate the materials handling process is the using of process charts [7], which is, in generally, realised on the object map of the production area *(Figure 2)*. Main advantages of this method are the using of real object characterisations and the presentation of the real distances and route possibilities among the objects. It can give suitable results for small and medium sized materials handling processes, but there is difficult and complicated to use it at complex systems (mainly if lots of material types can

be taken into account). In certain cases, relation lines can have different wide to demonstrate the importance of the given relations.

### 3.3. Materials handling graphs.

If we convert the handling process chart into a simple graph, we can have a general method to analyse the handling process by the devices of the graph theory and demonstrate the relations graphically *(Figure 3)*. Materials handling graphs are special charts in which the nodes mean the objects of the handling process and edges mean the handling relations [8]. Against the handling charts, graph does not contain information about the real geometry of the process, but uses mathematical approach for the calculations of the parameters. There are no application limits for the graphs in materials handling processes, but at large systems the using of graphs does not give clear and visible results about the relations.
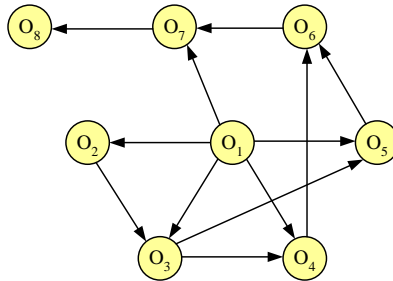


*Figure 3. Example for a handling graph*

### 3.4. Materials handling matrices.

Complex materials handling systems require methods which can handle all of the relations together and gives embraceable data for the design steps. Materials handling matrices give simple and easily usable solution for this task and they can be applied in all of the design steps of the handling processes, mainly in computer aided procedures [9].

Most of the materials handling matrices are two-dimension matrices and both dimensions contain the objects of the system, and the matrix elements contain the values of a certain material handling parameter:

$$\underline{\underline{H}}_{ij} = \begin{array}{c} \\ 1 \\ \vdots \\ i \\ \vdots \\ n_s \end{array} \begin{array}{c} 1 \ \cdots \ j \ \cdots \ n_d \\ \begin{bmatrix} & & & \\ & & & \\ & h_{ij} & & \\ & & & \\ & & & \end{bmatrix} \end{array} \tag{2}$$

where

  $i$ – source object,
  $j$ – destination object,
  $n_s$ – number of source objects [pcs],
  $n_d$ – number of destination objects [pcs],
  $h_{ij}$ – matrix element containing the value of a handling parameter.

Main advantage of the materials handling matrices, that certain parameters of the handling process can be easily calculated by matrix-operations (e.g. the analysis of the rows of the matrix gives information about the source objects etc.) [10].

## 4. Determination of materials handling matrices

The traditional design of a materials handling process is based on an existing or predefined object-arrangement, and determines the handling parameters using mainly different charts [11]. This concept cannot result a general design procedure, because of the predefined process elements. If handling relations may be separated from the objects, we could use general procedures during the design processes. To fulfil this requirement we can use materials handling matrices, which are generally applied in the design of materials handling [12].

If all of the handling relations are described in every detail, then the design steps can be realised. The main problem of this concept is the determination of the matrix elements, because the input data do not contain the required parameters directly. In generally, there are different methods for determining the handling relations with suitable knowledge and designer experiences, but the process depends on the given objects and their characterisations.

General procedure for the determination of the handling relations is the following:
1. Uncovering the technology abilities
2. Analysis of the product parameters
3. Definition of the served objects
4. Description of the relations among the objects
5. Determination of the values of the materials handling matrices

### 4.1. Uncovering the technology abilities.
Materials handling activities are served for fulfilling the requirements of production processes, so the material flow is suited to the production steps. Because of it, the first step of the design process to analyse the technology specifications of the system which have main effects to the handling process. The most important parameters of the technology are the following:
- number and types of the technology objects (machines, assembling places etc.),
- raw material needs of the objects,
- operations available at the objects,
- production capacities of the objects etc.

### 4.2. Analysis of the product parameters.
The main target of the technology process is to produce one (or more) product, which is realised through given production steps at determined technology objects. An object can realise one or more technology operations. Based on the above mentioned situation, the production steps of the product determine the relations of the technology objects, which depend on the main parameters of the product:
- involved machine elements,
- required operations,
- production sequence,
- produced quantity,
- produced variations etc.

### 4.3. Definition of the served objects.

Depends on the production sequence of the products and the characterisation of the technology objects, objects of the handling process can be allocated. If the products have different production sequences, then the served objects can be changed between the different time intervals of the production. If any of the objects can substitute another one, we have to previously determine the actual variation, but it can increase the complexity of the material handling process.

### 4.4. Description of the relations among the objects.

Based on the knowledge about the served objects and production structure, we can describe the relations among the objects and determine the element of the materials handling matrices. The simplest materials handling matrix is the relation matrix, which contains only the existence of the relations, but it is the basis of other handling matrices. General form of a relation matrix [5]:

$$\underline{\underline{R_{ij}}} = \begin{array}{c} \\ 1 \\ \vdots \\ i \\ \vdots \\ n \end{array} \begin{array}{c} 1 \quad \cdots \quad j \quad \cdots \quad n \\ \begin{bmatrix} & & & \\ & & & \\ & & r_{ij} & \\ & & & \\ & & & \end{bmatrix} \end{array} \tag{3}$$

where

$n$ – number of the served objects [pcs],

$r_{ij}$ – value of the relation matrix ($r_{ij} = 1$, if the relation exists, $r_{ij} = 0$ if the relation does not exist).

As the relation matrix contains only information about the existence of the relation, it is not enough for the determination of the handling parameters, so we have to apply other matrices too.

### 4.5. Determination of the values of the materials handling matrices.

Different materials handling matrices require variant parameters (see *Chapter 3*), so the determination procedure will be also different.

The most applied materials handling matrix is the material flow-intensity matrix [2], which contains the quantity of the material flowing between the objects of the given relation during an exact time interval:

$$q_{ij} = \frac{M_{ij}}{T} \tag{4}$$

where

$M_{ij}$ – quantity of the material moved in the given relation [kg],

$T$ – time interval [h].

Based on the equation above, we can fill the material flow-intensity matrix:

$$\underline{\underline{Q_{ij}}} = \begin{array}{c} \\ 1 \\ \vdots \\ i \\ \vdots \\ n \end{array} \begin{array}{c} 1 \quad \cdots \quad j \quad \cdots \quad n \\ \begin{bmatrix} & & & \\ & & & \\ & & q_{ij} & \\ & & & \\ & & & \end{bmatrix} \end{array} \tag{5}$$

If more than one material types (raw materials, elements, finished and semi-finished products etc.) are flowing in the handling system, then material flow-intensity matrix has to be determined for all of the material types, or a three-dimension (3D) matrix can be used, as follows:

$$\underline{\underline{Q_{ijk}}} = \begin{matrix} & \begin{matrix} 1 & \cdots & j & \cdots & n \end{matrix} \\ \begin{matrix} 1 \\ \vdots \\ i \\ \vdots \\ n \end{matrix} & \begin{bmatrix} & & & \\ & & q_{ijk} & & \\ & & & \end{bmatrix} \end{matrix} \tag{6}$$

where

$k$ – the flowing material type,
$m$ – the number of material types [pcs].

At complex production processes, the value of the 3D material flow-intensity matrix can be calculated by the equation below:

$$q_{ijk} = \sum_{l=1}^{p} o_{lj} \cdot a_{jk} \cdot f_{ik} \tag{7}$$

where

$l$ – type of the product,
$p$ – number of the types of the products [pcs],
$o_{lj}$ – element of the production matrix linked to the given object [pcs],
$a_{jk}$ – element of the requirement matrix linked to the given object [pcs],
$f_{ik}$ – element of the resource matrix linked to the given source object.

Production matrix *(O)* contains the produced quantities, and requirement matrix *(A)* contains the quantities of the used materials at the technology objects. The resource matrix *(F)* shows the source objects of the different material types. In generally, the value of the resource matrix is 1 or 0 (if $f_{ik} = 1$, then object $i$ is the source of material $k$, if $f_{ik} = 0$, then object $i$ is not the source of material $k$). If there are more than one source for a given material type, then the value of $f_{ik}$ can be between 0 and 1, but the next condition has to be fulfilled:

$$\sum_{i=1}^{n} f_{ik} = 1 \tag{8}$$

If the different material types are transported in the same loading unit, then the values of the intensity matrix can be summarised for the individual relations:

$$q_{ij} = \sum_{k=1}^{m} \left[ \sum_{l=1}^{p} o_{lj} \cdot a_{jk} \cdot f_{ik} \right] \tag{9}$$

## 5. Example for the determination of materials handling relations

For the demonstration of the determination method of materials handling relations, I will show a simple example, which presents the calculation procedure and the main aspects of a short manufacturing process.

In our example, there are eight technology objects in a small production hall and their main parameters are shown in *Table 1*.

*Table 1*
*Characterisations of the technology objects*

| Objects | Operation elements | Required material types | Required quantities [pcs/product] |
|---------|--------------------|-----------------------|----------------------------------|
| 1. | Operation A | $x_1$ | 1 |
| 2. | Operation B | $x_2$ | 2 |
| 3. | Operation C | $x_3$ | 1 |
| 4. | Operation D | $x_4$ | 2 |
| 5. | Operation E | $x_5$ | 1 |
| 6. | Operation F | $x_6$ | 4 |
| 7. | Operation G | $x_7$ | 1 |
| 8. | Operation H | $x_2$ | 1 |

Based on the data involved in *Table 1,* we can determine the elements of the requirement matrix $(a_{jk})$ *(Table 2)*. In our example, the used quantities at the objects are the same for all of the product types, so the using of a 2D matrix is adequate.

Next step of the design process is the analysis of the product types and their characterisations. *Table 3* contains the product types, their produced quantities and the technology objects used for the individual types.

*Table 2*
*Requirement matrix of the objects ($a_{jk}$)*

| Materials / Objects | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ |
|---------------------|-------|-------|-------|-------|-------|-------|-------|
| A | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| D | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| E | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| F | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| H | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

| | **Products** | **Produced quantities** [pcs/h] | **Object sequence** | | | |
|---|---|---|---|---|---|---|
| 1. | Product a) | 5 | A | B | E | F |
| 2. | Product b) | 10 | A | B | C | F |
| 3. | Product c) | 7 | G | H | E | F |

Based on the data involved in *Table 3,* we can also describe the production matrix $(o_{lj})$ of the products *(Table 4),* which contains the produced quantities of the individual products at the different technology objects during the given time interval.

| Objects / Products | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
|---|---|---|---|---|---|---|---|---|
| *Product a)* | 5 | 5 | 0 | 0 | 5 | 5 | 0 | 0 |
| *Product b)* | 10 | 10 | 10 | 0 | 0 | 10 | 0 | 0 |
| *Product c)* | 0 | 0 | 0 | 0 | 7 | 7 | 7 | 7 |

Using the information from *Table 3* we can determine the objects allocated to the given production processes and their relations *(Figure 4).*
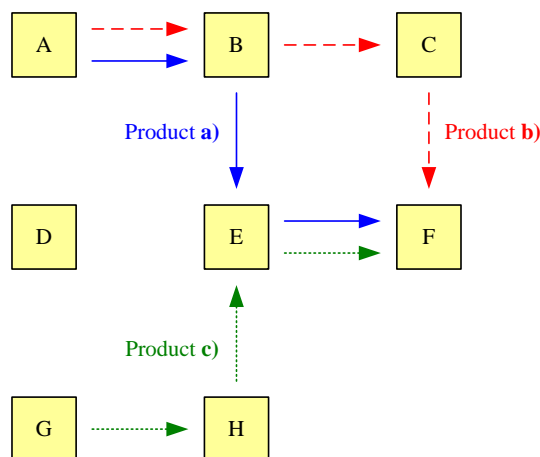


*Figure 4. Objects allocated to the product types*

Based on *Figure 4,* materials handling relation matrix can be determined for the example production system *(Table 5).*

*Table 5*
*Relation matrix of the handling process ($r_{ij}$)*

| Objects | A | B | C | D | E | F | G | H |
|---------|---|---|---|---|---|---|---|---|
| A | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| C | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| H | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

For the determination of the resource matrix *($f_{ik}$)* of the materials *(Table 6)* we have to separate the material types into three main categories:
- raw materials and elements *($x_i$),*
- interoperation semi-finished products *($y_i$),*
- finished products *($z_i$).*

Materials belonging to the first group come from an input store *(I)* to the technology objects, and finished products are transported to an output store *(U)* as an end operation. Only the semi-finished products have to be handled among the objects.

Resource matrix calculated for our example can be seen on *Table 6*.

*Table 6*
*Resource matrix of the materials ($f_{lj}$)*

| Objects | Raw materials | | | | | | | Semi-finished products | | | | | | | | | Finished products | | |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | $y_1$ | $y_2$ | $y_3$ | $y_4$ | $y_5$ | $y_6$ | $y_7$ | $y_8$ | $y_9$ | $z_1$ | $z_2$ | $z_3$ |
| I | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| U | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Applying the *(7) equation* on the data of *Table 2, 5* and *6,* material flow intensity matrix of the example system can be calculated, and the results are involved into *Table 7*.

| Objects | I | A | B | C | D | E | F | G | H | U |
|---------|---|---|---|---|---|---|---|---|---|---|
| **I** | 0 | 15 | 30 | 10 | 0 | 12 | 88 | 7 | 7 | 0 |
| **A** | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **B** | 0 | 0 | 0 | 10 | 0 | 5 | 0 | 0 | 0 | 0 |
| **C** | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 |
| **D** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **E** | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 |
| **F** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 |
| **G** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 |
| **H** | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 |
| **U** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Material flow intensity matrix of the example contains the summarized material flows, because the same handling unit is used for all of the material types.

By the help of the material flow intensity matrix most of the design tasks of the handling system can be realized.

## 6. Summary

The first step of the design procedure of materials handling systems is the analysis of the material flow and the calculation of the required handling parameters, which in many cases means the determination of the material handling relations. Main problems of this task are the calculation of the elements of relation matrices, because the parameters of the technology process are not the same as the required input parameters of the handling process.

In this paper I described the types, definitions, main characterisations, structures and determination methods of different materials handling matrices. The main result of this paper shows a determination method for the handling matrices which can be used in many design steps of the materials handling processes. The example, which I also presented, can help to understand the structure and calculation procedure of these matrices.

Next step of my research will be the realization of computer software which can calculate the relations and the elements of the handling matrices from the parameters of the production process, and use them in the design steps of the handling processes.

**References**

[1] CSELÉNYI, J.–ILLÉS, B. (ed.): *Logistic systems (in Hungarian).* Miskolci Egyetemi Kiadó, Miskolc, 2004.

[2] FELFÖLDI, L. (ed.): *Materials handling handbook (in Hungarian).* Műszaki Könyvkiadó, Budapest, 1975.

[3]   TELEK, P.: Equipment preselection for integrated design of materials handling systems. *Advanced Logistic Systems,* Vol. 7, No. 2 (2013), 57–66.

[4]   HANSEN, F.: *Methodical machine design (in Hungarian).* Műszaki Könyvkiadó, Budapest, 1969.

[5]   CSELÉNYI, J.–ILLÉS, B. (ed.): *Design and control of material flow systems I. (in Hungarian).* Miskolci Egyetemi Kiadó, Miskolc, 2006.

[6]   CSELÉNYI, J.–TELEK, P.: Mathematical modelling of collecting logistic system of used electronic products. In: CSELÉNYI, J.–BÁNYAI, T. (eds.): *Modelling and Optimisation of Logistic Systems – Theory and Practice.* University of Miskolc, Miskolc, 1999, 1–12.

[7]   FELFÖLDI, L.: *Design of materials handling processes (in Hungarian).* Műszaki Könyvkiadó, Budapest, 1969.

[8]   KULCSÁR, B.: *Industrial logistics (in Hungarian).* LSI Oktatóközpont, Budapest, 1998.

[9]   APPLE, J. M.: *Material handling system design.* John Wiley & Sons, New York, 1977.

[10]  OBÁDOVICS, J. GY.–SZARKA, Z.: *Mathematics at higher levels (in Hungarian).* Scolar Kiadó, Budapest, 2009.

[11]  KULWIEC, R. A.: *Materials handling handbook.* John Wiley & Sons, New York, 1985.

[12]  WU, L. H.–MOK, P. Y.–ZHANG, J.: An adaptive multi-parameter based dispatching strategy for single-loop interbay material handling systems. *Computers in Industry,* Vol. 62 (2011), 175–186.